Rotation and magnetic field effects on hadron yield in hadron resonance gas model

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Introduction

The primary objective of the ultra-Relativistic Heavy Ion Colliders at BNL and CERN is to study the properties of QCD matter under extreme conditions. At such high temperature and energy densities, a new state of matter is formed which behaves like a fluid with lowest viscosity to entropy density ratio. In the non-central collisions, the created fireball may generate a strong magnetic field and sustain rapid rotation for which large angular momentum is generated introducing vorticity to the fluid. Thus a comprehensive treatment should include variables like angular velocity and magnetic field as additional parameters to characterize the properties of hot and dense QCD matter. In addition to T and μ_B, vorticity or angular velocity (ω) and magnetic field (eB) act as additional control parameters which may influence the thermodynamics and phase diagram of QCD matter. While certain effects of finite baryon chemical potential (μ_B), angular velocity (ω) and magnetic field (eB), have been studied earlier [2].

The thermal properties of hot and dense QCD matter are commonly described in the framework of the of the hadron resonance gas (HRG) model, which is successfully describing the hadron yields and their ratios. In the present work, HRG model has been modified to incorporate the effect of magnetic field (eB) and vorticity (ω) on the hadron abundances and their ratios.

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HRG model including rotation and magnetic field

The free energy in the HRG model is approximated by the sum over partial pressure $p_i^{b/m}$ of hadrons and their resonances, which can be identified as charged or neutral particle [2]. The corresponding thermodynamic formulae governing the charged and neutral particles thus look different as shown below.

$$f_{i,c}^{b/m} = \mp \frac{T}{\pi R^2} \int \frac{dp_z}{2\pi} \sum_{n=0}^{\infty} \sum_{l=-n}^{N-n} \sum_{s_z=-s_i}^{s_i} \ln(1 \pm e^{-(\varepsilon_{i,c} - q_i\omega(l+s_z) - \mu_i)/T}), \tag{1}$$

where the dispersion relation contains the Landau levels

$$\varepsilon_{i,c} = \sqrt{p_z^2 + m_i^2 + |Q_i B|(2n - 2s_z + 1)} \tag{2}$$

The free energy density for the neutral particles [1] is given by

$$f_{i,n}^{b/m} = \mp \frac{T}{8\pi^2} \int_{(\Lambda_l^{\mathrm{IR}})^2} dp_r^2 \int dp_z \sum_{l=-\infty}^{\infty} \sum_{\nu=l}^{l+2s_i} J_\nu^2(p_r r) \times \ln(1 \pm e^{-(\varepsilon_{i,n} - (l+s_i)\omega - \mu_i)/T}) \tag{3}$$

where the free part of the energy dispersion is given by

$$\varepsilon_{i,n} = \sqrt{p_r^2 + p_z^2 + m_i^2} \ . \tag{4}$$

Here Q_i, $q_i = Q_i/|Q_i|$, s_i and m_i are the charge, sign of charge, spin and mass of the i^{th} hadron and the subscripts c and n refer to charged and neutral particles respectively. The upper (lower) signs correspond to the baryons (mesons) as denoted by the

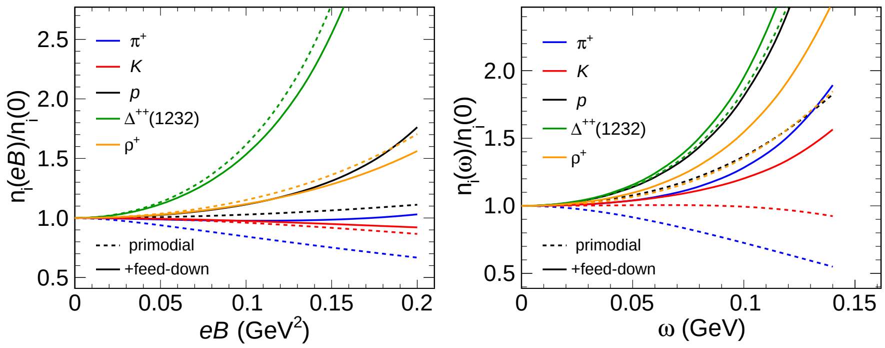

FIG. 1: Particle densities normalized to densities at vanishing magnetic field at $T = 0.155$ GeV as functions of magnetic field eB (left panel) and rotation ω (right panel).

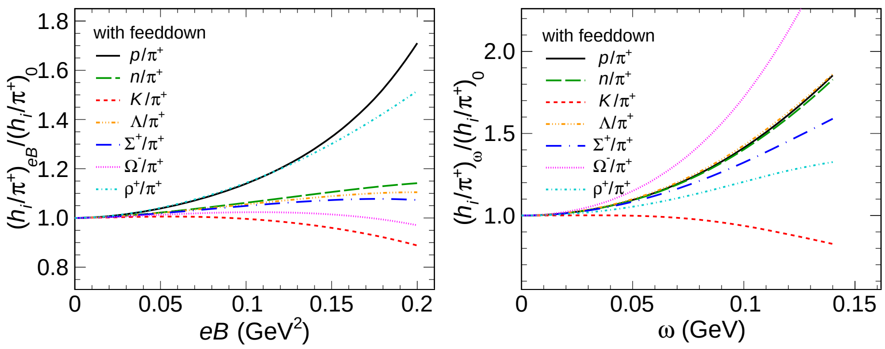

FIG. 2: Ratios of hadron to pion densities normalized to densities at vanishing magnetic field and rotation as functions of magnetic field eB (left panel) and rotation ω (right panel).

superscript b (m). The chemical potential $\mu_i = Q_{B,i}\mu_B + Q_{e,i}\mu_e + Q_{S,i}\mu_S$ reflects the baryonic, electric charge and strangeness components of the i^{th} particle. We have set $\mu_e = 0$ and $\mu_S = 0$ here for simplicity.

Results and Discussion

Figure 1 shows the relative change in the number densities of different hadrons in the presence of magnetic field and rotation. The present study is done for the temperature of $T = 155$ MeV and baryon chemical potential of $\mu_B = 0$. The densities of π^+ and K^+ are suppressed with increasing eB while the densities of p, Δ^{++} and ρ^+ increase with both eB and ω. There is clear mass ordering observed for spin-1/2 baryons and spin-0 mesons with exception of ρ^+ meson. A strong enhancement of Δ^{++} can be attributed to having spin-3/2 and doubly charged, which reduces the effective mass substantially. Figure 2 shows the relative change of number densities of different hadrons to pion ratios due to the effect of magnetic field and rotation. Maximum effect of magnetic field is observed for p/π ratio followed by ρ/π ratio. These ratios are expected to be most sensitive due to the presence of non-zero magnetic field. The primordial neutron yields are unaffected by the magnetic field, given that neutrons are neutral particles. A detailed study will be presented in the symposium.

References

[1] Y. Fujimoto, K. Fukushima and Y. Hidaka, Phys. Lett. B **816**, 136184 (2021).

[2] G. Mukherjee, D. Dutta and D. K. Mishra, Phys. Lett. B **846**, 138228 (2023).